Second generation biofuel production in the Netherlands. A spatially-explicit exploration of the economic viability of a perennial biofuel crop

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SECOND GENERATION BIOFUEL PRODUCTION IN THE NETHERLANDS

a spatially-explicit exploration of the economic viability of a perennial biofuel crop

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1. INTRODUCTION

Biofuel crops have received substantial research and policy attention as they may help mitigate climate change and improve energy security. Previous studies have shown that biofuel crops such as oilseeds, sugar and starch crops have substantial potential, especially when policies are implemented to promote the use of biofuel (EEA, 2007; de Wit and Faaij, 2010; Fischer et al., 2010; Perez-Soba et al., 2010). According to these studies, this potential is especially large in regions where production potential is high and costs are relatively low because of, amongst others, abundant land availability and thus relatively low land prices (e.g. in eastern Europe). Biofuel crop production is less likely in more densely populated European regions that are characterized by a limited amount of land and a capital- and knowledge-intensive farming sector.

Different approaches can be used to determine the potential for biofuel production. For example, in Perez-Soba et al. (2010) the potential for biofuel crop cultivation in the European Union was determined at a country level using a multi-model framework that combines a global economic model (LEITAP) and an integrated assessment model (IMAGE). Land supply curves indicating the relationships between land rental prices and land availability are applied to differentiate between the competitiveness of agricultural and biofuel feedstock production among regions. Accordingly, the allocation of these production systems is simulated, taking into account changes in climate and global demand for goods and commodities. Other approaches (e.g. de Wit and Faaij, 2010) determine the potential for biofuel production by assessing the available amount of surplus land that is not required to fulfil food supply, in order to calculate the total amounts of biofuel production that could result from biofuel crop cultivation on the surplus land. Such studies take a top-down approach and tend to focus on general agro-economic conditions and aggregate national or regional biophysical characteristics, without taking into account their local spatial variation. On the other hand, bottom-up studies take a local perspective and focus at the farm level to assess the conditions under which biofuels are likely to outcompete other crops (e.g. Van der Hilst et al., 2010; Mandryk et al., 2012). As these studies focus on specific, relatively small regions without considering other non-agricultural demands for land they cannot readily be used to depict potential changes in agricultural land-use patterns over larger areas.

This paper takes local conditions as a starting point and uses them to assess potential agricultural land-use changes over large areas. We simulate the local competition between different crops in a spatially-explicit manner, while taking account of others demands for land stemming from, for example, urbanisation and nature development. By aggregating these local land-use patterns we are able to estimate the total regional and national production volumes and land demand for various (biofuel) crops. These figures can then be used to validate existing top-down studies that rely on generalised conditions. This bottom-up approach has several advantages. We are able to show implications of increased spatial pressure on agricultural land use by incorporating the demand for land from non-agricultural land-use types that is often discarded in studies that solely focus on agricultural conditions. In addition we are able to produce spatially explicit simulations of the locations where biofuels are likely to be grown, and can thus offer information on, for example, potential landscape impacts and preferred locations for biofuel production facilities. This assessment is different from the more common top-down multi-level modelling approaches (e.g. Perez-Soba et al., 2010) that feed the regional demand from large-scale agro-economic models into fine-scale land-use allocation models to simulate potential land-use patterns because we are not using a prescribed regional demand. In our case the regional demand arises from local competition processes.

The approach is tested in a setting where biofuel crops are just one of many alternative land-use options and competition for land is considerable because of the demand from other societal sectors. This is especially interesting when hypothetical domestic biofuel stimulation policies are explored. Domestic biofuel production can be relevant to increase energy self sufficiency and security within a country, especially in a scenario of increased oil prices that make biofuel production more profitable and concurrently increase transportation costs of feedstock/biofuels production elsewhere.

As a case study, we explore the potential of second generation biofuels in The Netherlands, a densely populated country with a high pressure on land and an advanced agricultural sector. Based on a regional-level assessment of the potential of a perennial bioenergy crop (*Miscanthus giganteus*) in the Netherlands (Van der Hilst et al., 2010), a set of spatially-explicit driving forces for land-use change are fed into an economics-based land-use model (Land Use Scanner) to obtain a national assessment of the economic performance of this crop compared to other agricultural uses. This spatially-explicit land-use modelling approach accounts for both the simulation of local competition between different crops, and the demand for land stemming from, for example, urbanisation and nature development. Based on this analysis we make an estimate of the potential contribution of this specific crop to meet the target of 10% renewable energy use in the transport sector in the Netherlands, as assigned by the EU Directive on Renewable Energy (EC, 2009).

The remainder of the text is structured as follows. Section 2 describes the methodology applied to simulate the local competition and allocation of different (agricultural) land-uses. In Section 3 the main results are presented, followed by a discussion on the results and final conclusions (Section 4).

2. METHODOLOGY

In this section, the spatially-explicit methodology to determine the total land demand for biofuel production and related spatial patterns of cultivation will be discussed. Firstly, the land-use modelling approach will be described, followed by a discussion on the calibration of the modelling tool. Finally, a set of alternative policies on the agricultural sector will be presented in order to explore the outcomes of possible future developments.

2.1. Land-use modelling

In this assessment, the potential to grow biofuel crops in the Netherlands and spatial distribution of feedstock cultivation will be assessed through land-use modelling. Biofuel crops will be assumed to directly compete for land not only with arable farming rotation schemes and pastures according to their economic performance but also with urban, industry, infrastructure and nature development. The Land Use Scanner is used for simulating this competition and will allocate land to the land-use holding the highest socio-economic benefits. Land Use Scanner is a model based in economic and discrete choice theory that allocates 100x100m cells to competing land-use classes, based on local suitability (net socio-economic benefits derived from that location), the amount of available land and regional demand constraints per land-use type (Hilferink and Rietveld, 1999). In the model, local suitability is determined according to current land use; physical characteristics such as soil, groundwater level and relief; proximity to urban areas, infrastructure and other relevant places and zoning policies. On the basis of these characteristics, the model constructs suitability maps for each type of land use that are usually scenario-dependent. Using prescribed (ranges of) demand per land-use type, which are also scenario-dependent, the model simulates potential future land-use patterns reflecting scenario-conditions and an economic rationale. However, demands do not have to be necessarily assigned for all classes. If this is the case, the magnitude of allocation of the land-uses that were not assigned will depend on their relative local suitability in comparison to other classes and on the amount of surplus land that is not requested to fulfil the demand explicitly assigned to the other land-uses. In this application the demand for urban land-use types is prescribed (based on underlying sector-specific models), but agricultural land demand is flexible. The total amounts of allocated land thus depend on the outcome of the local competition. A more extensive description on model basics, typical applications and calibration efforts is provided elsewhere (see: Loonen and Koomen, 2009; Koomen and Borsboom-van Beurden, 2011).

The model aims to mimic a land market in which land-use classes represent actors that want buy a land parcel for a specific purpose: growing a particular crop or building a house. The local suitability values thus represent their initial bid for that location based on the socio-economic benefits they expect to obtain. This valuation process differs among bidders according to the parcel's properties and the amenities each one can derive from them. Different methods are applied to assess local suitability values: statistical analysis explaining observed land-use patterns, expert judgement and utility-based frameworks such as hedonic pricing methods. In order to specify the suitability for agricultural land use we use the expected Net Present Value for crops. The next section further discusses that approach. For the non-agricultural land-use types the definition of local suitability relies previous studies in which expert judgement was applied to arrive at a likely bid price (Koomen et al., 2008).

2.2. Assessing agricultural economic performance

While making land-use decisions, farmers account for expected profitability to choose among different crops. The net present value (NPV) is a standard method to appraise long-term projects, by measuring discounted time series of expected cash flows. The NPV that a farmer can expect by producing a certain crop in a land parcel depends on the specific costs to produce that crop, on the market prices of products and co-products and on the yields that can be obtained, which in turn are directly related to the properties of that parcel. Therefore, the NPV provided by a crop can be regarded as a proxy for the price a farmer is willing to bid for a land parcel (i.e. suitability of cell c for land use i) based on its specific local properties:

$$\mathrm{NPV}_{c,i} = \sum_{y=0}^{n} \frac{B_{c,i,y} - C_{c,i,y}}{(1+r)^{y}} \qquad \text{(Eq. 1)}$$

where:
NPV is the net present value derived from land-use i in cell c in year 0; and
$B_{c,i,y}$ and $C_{c,i,y}$ are the benefits and costs respectively (including the initial investment in year 0) of land-use i in cell c in year y, r is the discount rate and n is the lifetime of the project.

The costs related to crop production include four main categories of expenses: land costs, field operation costs (contractor, machinery, labour and diesel costs), input costs (seeds, fertilizers and pesticides), fixed costs (insurance, soil sample assessment, etc.) and storing costs. Thus, the costs for producing a specific crop are calculated as:

$$C_{c,i,y} = LC + FOC_{i,y} + IC_{i,y} + FC_{i,y} + \sum_{p=1}^{n} Y_{c,p} * SC_{p,y} \qquad \text{(Eq. 2)}$$

where:
$C_{c,i,y}$ are the total costs resulting from land-use i in cell c in year y
LC are the land costs
$FOC_{i,y}$ are the field operation costs resulting from land-use i in year y
$IC_{i,y}$ are the input costs resulting from land-use i in year y
$FC_{i,y}$ are the fixed costs resulting from land-use i in cell c in year y
p is a (co-)product generated by land-use i
n are the number of products and co-products generated by land-use i
$Y_{c,p}$ is the yield of (co-)product p in cell c
$SC_{p,y}$ are the storing costs of (co-)product p in year y

The benefits of crop production are the revenues from selling the main product, selling the co-product and CAP subsidies for crop production. They are strongly related to local biophysical characteristics and calculated as follows:

$$B_{c,i,y} = S_{i,y} + \sum_{p=1}^{n} Y_{c,p} * P_{p,y} \qquad \text{(Eq. 3)}$$

where:
$B_{c,i,y}$ are the benefits derived from land-use i in cell c in year y
$S_{i,y}$ is a subsidy per unit of land-parcel area using land-use i in year y
p is a (co-)product generated by land-use i
n are the number of products and co-products generated by land-use i
$Y_{c,p}$ is the yield of (co-)product p in cell c
$P_{p,y}$ is the price of (co-)product p in year y

The biophysical suitability of a cell for a particular crop can be depicted by yield reduction maps, which express the fraction of the maximum attainable yield that can be met when local biophysical conditions are not optimal for that crop. Thus, these maps can be used to differentiate the yield and consequently the NPV that can be derived from different crops according to their location. We applied the most recent versions of crop-specific yield reduction maps that were initially developed to evaluate local biophysical conditions in preparation for land-use development projects (*Her-Evaluatie Landinrichtings Project* in short *HELP*). In this method, physical yields are determined by a combination of soil characteristics (e.g. clay–sand–peat ratios, rooting depth and stoniness) and water tables in summer and winter (Brouwer and Huinink, 2002). The total yield reduction (D_{tot}) relative to the maximum potential yield is determined by the yield reduction caused by drought (D_{dr}) and the yield reduction caused by water surplus (D_{wa}) assuming no irrigation:

$$\mathrm{D_{tot}} = \mathrm{D_{wa}} + \left[\frac{100-\mathrm{D_{wa}}}{100} * \mathrm{D_{dr}}\right] \qquad \text{(Eq. 4)}$$

Data on costs and revenues related to biofuel and arable crops production in the Netherlands have been gathered in a previous assessment on the economic performance of biofuel crops production in a region of the Netherlands (Van der Hilst et al., 2010). These cash-flows are then used as an input to calibrate the model and calculate the resulting NPV's for each cell and crop. Accordingly, crop allocation according to economic performance is simulated.
An annuity time period of 20 years will be considered, which is the lifetime of the perennial crops (Van der Hilst et al., 2010) and also a common time horizon in other cash-crop studies (Stonehouse et al., 1988; Kuhlman et al., 2012). A discount rate of 5.5% is assumed, which is a realistic interest rate for farmer loans (de Wolf and van der Klooster, 2006, cited by Van der Hilst et al., 2010). For arable farming, two rotation schemes will be considered, one suited for clay soils and another for sandy soils (Table 1),

Table 1. Crop rotation schemes in arable farming (Source: van der Hilst, 2010)

Crop	Clay rotation	Sand rotation
Winter wheat	0.20	-
Summer barley	0.10	0.28
Winter barley	-	0.06
Industrial potato	0.15	0.30
Sugar beet	0.10	0.20
Maize	0.25	0.04
Other	-	0.06
Fallow	0.05	0.04

2.3. Exploring variations on future developments

Since future conditions in the land-use system are highly uncertain, a number of different variations on a future scenario are designed to explore the outcomes of possible policy alternatives up to 2030. Scenarios translating IPCC's SRES narratives (IPCC, 2000) to future developments on socio-economic and demographic factors in the Netherlands have been created by several Dutch research institutes (CPB et al., 2006). By applying these scenarios in sector-specific models developed by Dutch institutes, the future land demand for, for example, urban development, industry, infrastructure and nature was determined. A more extensive description of the scenario storylines, the application of sector-specific models and resulting land-use patterns is discussed elsewhere (Riedijk et al., 2007; Koomen et al., 2008).

In this assessment, a scenario based on the IPCC-A1 narrative is used as a reference alternative upon which variations in the agricultural system and policy will be considered. The main assumptions of this scenario (in terms of, for example, land demand for urban development) will thus remain the same irrespective of the considered policy alternative. The remaining land will be considered as available for competition among arable farming, pastures and biofuel crops according to their economic performance. No predefined demand ranges were set for these agricultural land-use types.

The reference alternative will result from a combination of the A1 scenario with the calibration of the model according to the economic data on agricultural production systems gathered by van der Hilst et al. (2010). Agricultural production in EU is subsidized according to the Common Agriculture Policy (CAP). Under the current configuration, subsidies for arable farming crops range between 265 and 446€/ha, while for biofuel crops they are much lower (45€/ha).

Reforms on CAP policies have been under discussion in recent years and it is still uncertain which outcomes will result from current negotiations. Nevertheless, a policy shift can be observed in recent years, with subsidies being decoupled from production levels and allocated to promoting the provision of environmental services instead. Nowadays CAP is regarded as an important mechanism to stimulate the provision of public goods through agriculture (Cooper et al., 2009). Suggested applications include the mitigation of climate change by reducing greenhouse gas emissions and promoting carbon storage. Biofuels are expected to play an important role in tackling climate change and are envisaged as an important renewable energy source (EC, 2009). Therefore, a policy alternative will be considered in which biofuel crops will receive the same maximum CAP subsidy (of 446€/ha per year) as arable farming. To allow a fair comparison we maintain current subsidies also for these other types of arable farming.

Empirical studies have shown that market-distorting agricultural policies in OECD countries hamper development and welfare in developing countries (e.g. Winters, 2005; Anderson and Valenzuela, 2007). Therefore, some argue that a further reduction of subsidies is needed to provide globally fair conditions for competition. To study the impact of such a policy change we also consider a policy alternative in which all subsidies for arable farming crops are abolished. This will allow to study to what extent biofuel crops are able to compete with other agricultural land-uses in the absence of market distorting policies.

According to a previous assessment on economic performance of miscanthus cultivation(Van der Hilst et al., 2010), large investment costs up to 3600€/ha (around 80% of total costs in year 1) are required in the first year for acquisition of rhizomes, making this crop not competitive with others. Thus, a policy alternative is considered that stimulates biofuels by covering the investment costs required for seed acquisition in the first year. Moreover, an additional policy alternative is considered that combines a CAP biofuel subsidy increase and a subsidy on miscanthus seeds.

The aforementioned policy alternatives are summarized below in Table 2.

Table 2. Overview of the policy alternatives considered in this study

ID	Policy alternative	Removal of CAP subsidies for arable farming crops	CAP biofuel crops subsidies equal to arable farming crops	Seeds subsidy
#1	*Reference*	No	No	No
#2	*CAP*	Yes	No	No
#3	*CAP Biofuel*	No	446€/ha per year	No
#4	*Investment*	No	No	3600€/ha in year 1

3. RESULTS

The results obtained by simulating the considered policy alternatives are summarized in *Table **3***. It can be concluded that under reference conditions, miscanthus cultivation is to some extent viable in the Netherlands when comparing its economic performance with other agricultural land-uses. Although the spatial distribution of location where miscanthus is economically viable spreads all over the country's territory, the north- and south-eastern provinces appear to be those where miscanthus cultivation is more attractive (*Figure **1***). Nevertheless, the resulting feedstock would only allow to produce roughly 1% of the current energy demand for transport fuel.

Table 3. Simulation results for different policy alternatives

Land-use / Policy alternative	#1	#2	#3	#4
Arable Farming (ha)	637,833	24,773	619	41,149
Pastures (ha)	1,256,514	1,258,739	52	283
Biofuel crops (ha)	92,533	702,766	1,996,445	1,951,815
Biofuel potential				
Biofuel crop annual yield (odt kton)[1]	989	8,576	23,594	23,042
Biofuel annual production (TJ)[2]	6.2	54.0	148.6	145.2
Share in current energy consumption of Dutch transport sector[3]	1.0%	8.9%	24.3%	23.8%

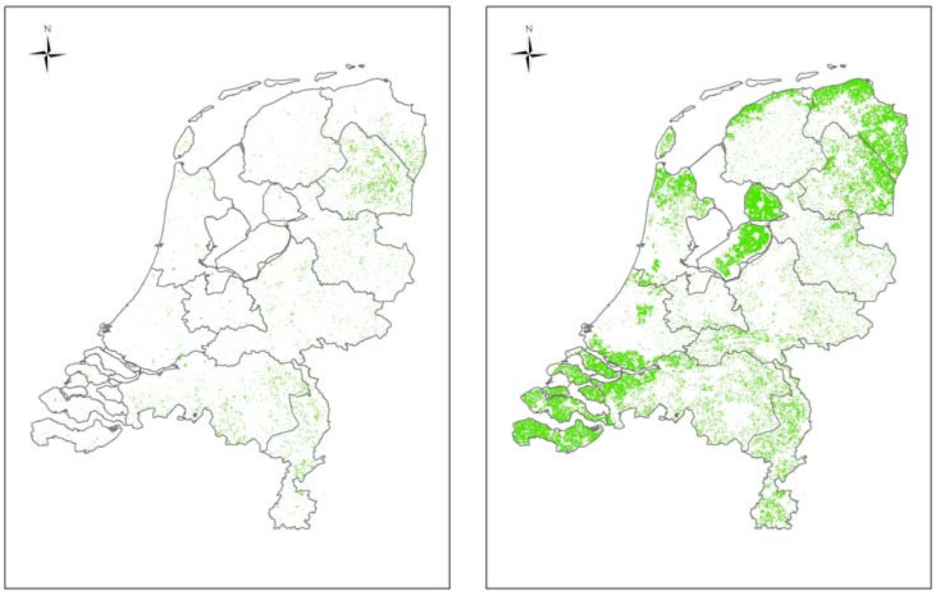

Figure 1. Spatial distribution of the locations in the Netherlands where miscanthus cultivation is economically viable according to policy alternative #1 (left) and #2 (right).

However, if CAP subsidies to arable farming crops were removed altogether (policy alternative #2), agriculture would become much less competitive, showing a lower performance than miscanthus and pastures in a large part of the available agricultural land. In fact, agriculture would remain economically attractive only in 4% of the amount of land assigned to this land-use in the reference scenario, being miscanthus a more preferable crop in the majority of this land. Concurrently, if all land where miscanthus cultivation is more profitable was used for that purpose, this would allow to produce biofuel enough to cover almost 9% of the oil-based fuel consumption in the Dutch transport sector.

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[1] Maximum annual attainable yield of miscanthus in the Netherlands is assumed to be 15 odt/ha (Christian and Riche (1999), Clifton-Brown et al. (2004) and Elbersen et al. (2005), cited by Van der Hilst et al., 2010). The calculated annual yield takes into account spatially-explicit yield reduction due to the occurrence of local suboptimal biophysical conditions.

[2] Energy content (LHV) of miscanthus is assumed to be 18 GJ/odt (Christian et al. (2001), cited by Van der Hilst et al., 2010). The conversion efficiency of lignocellulose conversion of miscanthus biomass to ethanol is assumed to be 35% (Hamelinck et al. (2005), cited by Van der Hilst et al., 2010)

[3] Final Energy Consumption of oil products by the transport sector in the Netherlands was 610.7 PJ in 2009 (EUROSTAT, 2011)

While assessing policy alternatives #3 and #4, it could be concluded that if either an investment subsidy or higher CAP subsidies were provided for growing miscanthus, this crop would become the most attractive option in almost all available agricultural land (*Figure **2***). According to *Table **3***, it can also be concluded that, on the one hand, pastures would be the agricultural land-use performing poorer in such policy settings; and on the other hand, the economic performance of miscanthus cultivation would benefit more from CAP payments comparable to those provided to arable farming than a subsidy on the acquisition of the rhizomes. Nevertheless, the biofuel potential resulting from these policy alternatives would be roughly the same, around 24% of the current transportation fuel consumption.

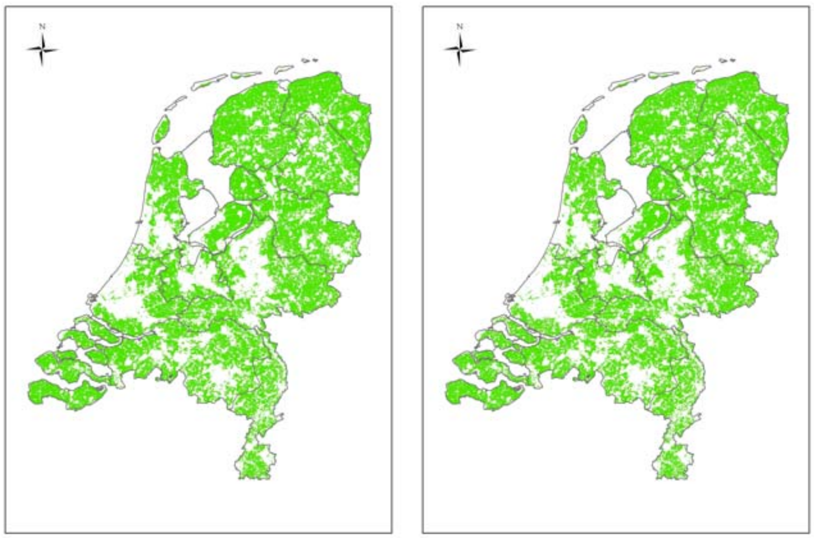

Figure 2. Spatial distribution of the locations in the Netherlands where miscanthus cultivation is economically viable according to policy alternative #3 (left) and #4 (right).

4. CONCLUSION AND DISCUSSION

The proposed method allows the determination of the production potential of second generation biofuel with domestic feedstock and their related spatial distribution of feedstock cultivation in the Netherlands, a country characterised by high-pressure on land and conflicting land-claims. It could be concluded that under large-scale cultivation of a perennial biofuel crop in the Netherlands can be economically viable current conditions. Furthermore, a number of regions have been identified where miscanthus cultivation is more attractive, namely the north- and south-east of the country. These are the regions where intensively-managed arable farming crops are less productive, thus generating less benefits to compensate for the large input and operation costs. Therefore, a perennial crop requiring low inputs and less intensive farming practices such as miscanthus could become an interesting option. However, the resulting biofuel production potential is relatively low, only accounting for 1% of the fuel consumption in the transport sector in the Netherlands.

This method also allowed studying different alternatives of future developments, namely by exploring the outcomes of diverse policy schemes. It was demonstrated that biofuel potential could be further increased through the implementation of policies supporting biofuel crop cultivation such as subsidy schemes and favourable financial incentives.

The present study indicates that a removal of CAP payments is likely to considerably affect the economic viability of current forms of arable farming in the Netherlands. In fact, according to this policy alternative, arable farming will be outcompeted by biofuel crops and pastures in most part of the country. Arable farming crops will remain only in areas where high yields and thus higher profits can be obtained. This outcome is in line with assessments on the viability of farming in the EU that also demonstrated that farmers are vulnerable to changes in CAP payments (Vrolijk et al., 2010). While this situation could indeed create favourable conditions for the competitiveness of biofuel crops and increase the biofuel production potential, it would severely undermine food security in the Netherlands.

Furthermore, our analysis shows that financial incentives for biofuel crop cultivation similar to the current CAP payments to arable crop farming will provide such an advantage to biofuel crops that they will probably outcompete current agricultural practices. This may dramatically influence production chains, ecological and landscape values currently associated with agriculture in the Netherlands. The study thus provides a warning to policy-makers to acknowledge the importance of economic factors in land-use dynamics when designing policy instruments to promote biofuels. Most importantly, the sensitivity of these dynamics to a number of economic factors should be thoroughly understood prior to providing financial incentives. Therefore, further research on analysing the sensitivity of land-use dynamics to factors such as commodity market prices, subsidies and discount rate is recommended.

It should be noted, however, that the obtained results are largely caricatural, since such dramatic land-use changes are neither expected nor desirable to occur. In fact, land-use systems often show stability and resilience to disturbances and external influences, due to the characteristics of both ecological and social systems (Verburg et al., 2002). For instance, when prices of certain agricultural commodities fall, farmers will wait a few years depending on the investments made, instead of immediately changing their cropping system. Moreover, farmers may to some extent be averse to change, due to the need of investing in new machinery and engaging in practices that may require a learning period before optimal outcomes are attained. In some cases, financing may even be difficult to obtain, particularly for small producers. Other aspects may also play a role, such as traditional practices in family farms, conservation of highly regarded cultural landscapes and alternative uses to agriculture (e.g. sightseeing, rural tourism). Consequently, sudden changes in (economic) factors do not immediately result in a change of the structure of the land-use system. However, the economic performance of the different agricultural options was assumed to be the only driver of land-use change and therefore these processes have not been properly addressed within the present modelling framework. Further research is thus required to find methods able to explicitly quantify these processes in economic modelling.

In addition, some other comments can be made in relation to the presented study. Firstly, factors related to economies of scale were not taken into account in this analysis. For instance, cultivation of biofuel crops is likely to be clustered in areas surrounding biofuel refinery plants, even though that is not necessarily the most suitable option in all land parcels. This clustering process will take place when the minimisation of transportation costs and optimisation of field operations compensates for lower initial yields. The incorporation of this process into the current model is hampered by a lack of exact financial information on the benefits of agglomeration. Thus the determined potential for biofuel production should be interpreted with caution. This assessment can be used, however, to identify the key areas that are more suitable for biofuel crop cultivation and thus help to pinpoint potential locations for biofuel refineries.

Secondly, prices were assumed to remain the same for a period of 20 years while in fact commodity market prices can fluctuate strongly over such a long period. Furthermore, by assuming endogenous prices, the modelling framework fails to incorporate price formation processes and their possible feedbacks. For instance, if a CAP subsidy for biofuel crops was provided at European level, that would imply that other countries could also benefit from the same competitive advantages and as a result biofuel crop production could be expected to generally increase. A surge on the supply of biofuel crops could then potentially lead to a decrease in their prices, thus decreasing the competitiveness of biofuel crops over other agricultural land-uses. The use of endogenous prices might therefore provide an explanation to the apparent overestimation of biofuel potential in the policy alternatives assuming subsidies for biofuel crops. However, since this assessment aimed to replicate the decision-making process of farmers, using recent average market prices while determining the NPV can still be deemed as an appropriate approach, as this is the type of information that is most readily available for farmers.

Furthermore, input and field operation costs were also assumed to be the same irrespectively of the soil suitability, when farm management practices and technology can actually vary in order to adapt to different biophysical conditions. Nevertheless, although this assumption limits the scope of the analysis by not taking into account the existing variability on farmers' strategies and preferences, it still presents an indication of the relative profitability of different agricultural land uses when comparable management practices are implemented.

It would be interesting to take the role of uncertainty and cost reversibility in the adoption of energy crops by farmers into consideration in this analysis. Farmers may, for example, prefer to continue cultivating a crop that is less profitable but is also less fraught with uncertainty than switching to and investing in a more profitable crop that is associated with higher market/policy risks. In this context, real option valuing (ROV) might be an alternative method worth to explore in further analysis (Song, 2010).

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